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METHODS FOR DESIGN AND EVALUATION OF INTEGRATED
HARDWARE/SOFTWARE SYSTEMS FOR CONCURRENT COMPUTATION

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This report briefly summarizes research activities and publications under this grant during the second six months of funding (9/15/84 - 3/14/85).

Summary of Research Activities

The major tasks that have been performed are the following:

1. *VAX implementation of the PISCES parallel programming environment.* The implementation of the PISCES Fortran 77/Unix-based programming environment was successfully completed on the DEC VAX under Unix 4.1bsd and 4.2bsd. The system is currently running at ICASE and at the University of Virginia and has been used for several applications of moderate size (discussed below).

2. *Apollo workstation network implementation of the PISCES environment.* The PISCES system was successfully implemented on a local network of Apollo workstations (10 Apollo DN 300 workstations on an Ethernet-like local network). This system implements the same PISCES virtual machine that is available on the VAX, so that applications programs may run on either system without change in the code. The programmer sees the workstation network as a single clustered parallel machine. Each workstation implements a PISCES cluster. The programmer may distribute various parallel applications tasks to these clusters using the PISCES Fortran commands.

In constructing this implementation no attempt was made to optimize performance; we used the same basic implementation strategy as on the VAX. The goal was simply to

produce a first prototype for a study of the viability of this sort of PISCES implementation. After implementation was complete, Nancy Fitzgerald studied the basic performance of the system (as part of her Master of Science thesis [5], which also involved the implementation of the Apollo system). The basic performance parameters are the time to initiate a task and the time to send a message. Due to the amount of disk access involved in both activities on the Apollos both task initiation and message passing were found to be unacceptably slow for realistic applications. To improve this performance we would have to change the operating system on the Apollos, which is not currently possible. As a result we do not intend to pursue this implementation at present.

3. *FLEX implementation of the PISCES environment.* Implementation of the PISCES system on the FLEX/32 at NASA Langley is the highest priority item in our current activities. Preliminary design work has been done, but detail design has been delayed awaiting release of FLEX software documentation by the manufacturers. Implementation is planned for summer 1985.

4. *Sparse matrix iterative solver in PISCES Fortran.* Merrell Patrick of Duke University, in a collaborative effort with this project, designed a series of six variations on a general parallel solution package for sparse matrix representations of linear systems of equations. These six variations were implemented in PISCES Fortran and run on the VAX implementation of PISCES at ICASE. The variations included a data flow version, two chaotic iterations, and various forms of communication (broadcast, direct send, etc) between the tasks. These were used for system test and to measure differences in the number of messages and the communication patterns between the different parallel versions. We found that even the relatively small ICASE VAX 750 provided acceptable performance for these studies, which involved about 15 parallel tasks and up to several hundred messages. This work was presented by Prof. Patrick at a workshop on parallel numerical methods at the University of Texas in Austin hosted by David Young; a short paper will also be published [1].

5. *Image processing application of PISCES.* Prof. Worthy Martin and Ph.D. candidate Chew-lim Tan of the U.Va. Computer Science Department are using the PISCES system for an application of artificial intelligence techniques to an image processing problem: the tracking of moving objects in dynamically changing scenes. Parallel tasks are used to locate and track different objects within the scene, which is continuously changing as new inputs arrive from the camera. This work illustrates the potentially broad application of the PISCES system, but is not supported directly by this grant.

6. *Theoretical studies.* A new formal model of concurrent computation has been developed by P.D. Stotts in a Ph.D. thesis nearing completion. The model is based on the mathematical system known as "H-graph semantics" (developed by the principal investigator) together with a "timed Petri net" model of the parallel aspects of a system. Stotts has shown that the model can be used for timing analyses of hierarchical parallel systems and for automatic detection and resolution of conflicts in concurrent access to shared data. We hope to use an extension of this model as the basis for a formal definition of the PISCES virtual machine, which would be potentially of value to the PISCES implementor and user. A paper on this work will be presented at a workshop in Europe in summer 1985; a technical report has been published [2].

7. *Publications.* A journal paper describing the PISCES design has been accepted for publication in *IEEE Software*, July 1985; a prepublication version is available as an ICASE technical report [3]. A Ph.D. dissertation by P.D. Stotts [4] and an M.S. thesis by N. Fitzgerald [5] are nearing completion. J. Taylor completed an informal project report [6] as part of his Master of Computer Science degree describing his implementation of a performance monitoring and analysis package for the VAX implementation of PISCES.

Publications List

- [1] Patrick, M. and T.W. Pratt, "Communications Oriented Programming of Parallel Iterative Solutions of Sparse Linear Systems," *Communications in Applied Numerical Methods*, (to appear). Paper presented at the Workshop on the Impact of Parallel Architectures

on Numerical Methods, U. of Texas at Austin, March 1985.

- [2] Stotts, P.D. and T.W. Pratt. "Hierarchical Modeling of Software Systems with Timed Petri Nets," International Workshop on Timed Petri Nets, Torino Italy, July 1985 (to appear). Also published as Report 85-01, Computer Science Dept. Univ. of Virginia, January 1985, 19 pp.
- [3] Pratt, T.W. "PISCES: An Environment for Parallel Scientific Computation," *IEEE Software*, July 1985 (to appear). Also published as ICASE Report 85-12, ICASE, NASA Langley Research Center, Hampton, VA, February 1985, 30 pp.
- [4] Stotts, P.D. *A Hierarchical Graph Model of Concurrent Software Systems*, Ph.D. dissertation, Computer Science Dept., Univ. of Virginia (to appear).
- [5] Fitzgerald, N.J. *Implementation of a Parallel Programming Environment*, M.S. thesis, Computer Science Dept., Univ. of Virginia, May 1985, 80 pp.
- [6] Taylor, J.A., "Performance Analyzer for the PISCES System," M.C.S. Project Report, Computer Science Dept., Univ. of Virginia, December 1984, 13 pp.